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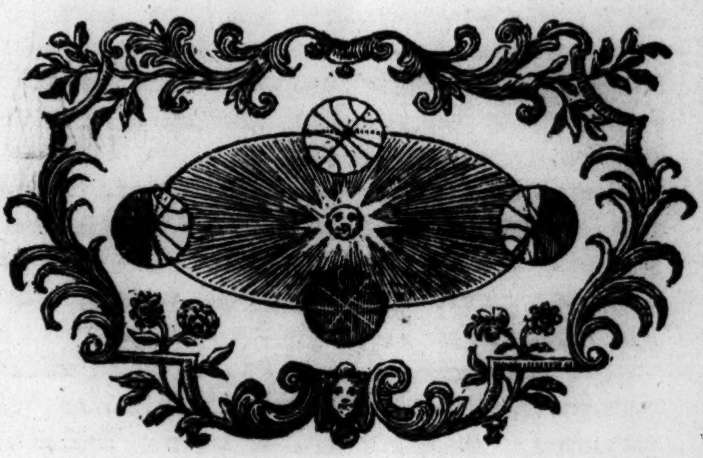
THE DESCRIPTION and USE OF A NEW MACHINE, CALLED The Mechanical Paradox;

Invented by

JAMES FERGUSON, *F.R.S.*



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THE

DESCRIPTION AND USE

OF THE

MECHANICAL PARADOX.

THE vulgar and illiterate take almoſt every thing, even the moſt important, upon the authority of others, without ever examining it themſelves.—Although this implicit confidence is ſeldom attended with any bad conſequences in the common affairs of life, it has nevertheleſs, in other things, been much abuſed; and in political and religious matters, has produced fatal effects. On the other hand, knowing and learned men, to avoid this weakneſs, have fallen into the contrary extreme: ſome of them believe every thing to be unreaſonable, or impoſſible, that appears ſo to their firſt apprehenſion; not adverting to the narrow limits of the human underſtanding, and the infinite variety of objects, with their mutual operations, combinations, and affections, that may be preſented to it.

It muſt be owned, that credulity has done much more miſchief in the world than incredulity has done, or ever will do; becauſe the influences of the latter extend only to ſuch as have ſome ſhare of education, or affect the reputation thereof.—And ſince the human mind is not neceſſarily impelled, without evidence, either to belief or unbelief; but may ſuſpend its aſſent to, or diſſent from, any propoſition, till after a thorough examination; it is to be wiſhed, that men of literature, eſpecially philoſophers, would not haſtily, and by firſt appearances, determine themſelves with reſpect to the truth or falſhood, poſſibility or impoſſibility of things.

A perſon who has made but little progreſs in the mathematics, though in other reſpects learned and judicious, would be apt to pronounce it impoſſible that two lines, which were no where two inches aſunder, may continually approach toward one another, and yet never meet, though continued to infinity: and yet the truth of this propoſition may be eaſily demonſtrated.—And many, who are good mechanics, would be as apt to pronounce the ſame, if they were told, that though the teeth of one wheel ſhould take equally deep into the teeth of three others, it ſhould affect them in ſuch a manner, that, in turning it any way round its axis, it ſhould turn one of them *the ſame way*, another *the contrary way*, and the third *no way at all*.

On a very particular occaſion, about fourteen years ago, I contrived a ſmall machine of this ſort, which has been ſhewn and explained to many; and which I ſhall here deſcribe, and explain ſome of the uſes it has been applied to.

It is repreſented to view by Fig. 1. in which, *A* is called *the immoveable plate*, becauſe it lies ſtill on a table whilſt the machine is at work. *B C* is a moveable frame, to be turned round an upright axis *a* (fixt into the center of the immoveable plate) by taking hold of the knob *n*, which is fixt into the index *b*.

On the ſaid axis is fixt the immoveable wheel *D*, whoſe teeth take into the teeth of the thick moveable wheel *E*, and turn it round its own axis, as the frame is turned round the fixt axis of the immoveable wheel *D*; and in the ſame direction that the frame is moved.

The teeth of the thick wheel *E* take equally deep into the teeth of the three wheels *F*, *G*, and *H*; but operate on theſe wheels in ſuch a manner, that whilſt the frame is turned round, the wheel *H* turns *the ſame way* that the wheel *E* does; the wheel *G* turns *the contrary way*, and the wheel *F* turns *no way* at all.

Before we explain the principles on which theſe three different effects depend, it will not be improper to fix ſome certain *criteria* for bodies turning or not turning round their own axes or centers; and to make a diſtinction between abſolute and relative motion.

1. If a body ſhews all its ſides progreſſively round toward a certain fixed point in the heavens, the body turns round its own axis or center, whether it remains ſtill in the ſame place, or has a progreſſive motion in any orbit whatever.—For, unleſs it does turn round its own center, it cannot poſſibly have one of its ſides toward the weſt at one time, toward the ſouth at another, toward the eaſt at a third time, and toward the north at a fourth.—This is the caſe with the moon, which always keeps one ſide toward the earth; but ſhews the ſame ſide to every fixed point of the ſtarry heaven in the plane of her orbit, in the time ſhe goes once round her orbit; becauſe in the time that ſhe goes round her obit, ſhe turns once round her own axis or center.—On the contrary, if a body ſtill keeps one of its ſides toward a fixed point of the heaven, the body does not turn round its own axis or center, whether it keeps in one and the ſame place, or has a progreſſive motion in any orbit or direction whatever.—This is the caſe with the card of the compaſs in a ſhip, which ſtill keeps one of its points toward the mag-

netic north, let the ſhip be at reſt, or ſail round a circle of many miles diameter.

Both theſe caſes may be exemplified either by a cube or a globe, having a pin fixt into either of its ſides to hold it by: we ſhall ſuppoſe a cube, becauſe its ſides are flat.—Sit down by a table, and hold the cube by the pin, which may be called its axis, and keep one of its ſides toward any ſide of the room. Whilſt you do this, you do not turn the cube round its axis, whether you ſtill keep it in the ſame place, or carry it round any other fixed body on the table.—But if you try to keep any ſide of the cube toward the fixed body, whilſt you are carrying it round the ſame, you will find that you cannot do ſo, without turning the pin round (which is fixt into the cube) betwixt the finger and thumb whereby you hold it; unleſs you riſe and walk round the table, keeping your face always toward the fixed body on the table; and then, both yourſelf and the cube will have turned once round; for the cube will have ſhewn the ſame ſide progreſſively round to all ſides of the room, and your face will have been turned toward every ſide of the room, and every fixed point of the horizon.

2. If a ſhip turns round, and at the ſame time a man ſtands on the deck without moving his feet, he is turned abſolutely round by the motion of the ſhip, tho' he has no relative motion with reſpect to the ſhip. —But if, whilſt the ſhip is turning round, he endeavours to turn himſelf round the contrary way; he thereby only undoes the effect that the turning of the ſhip would otherwiſe have had upon himſelf: and is, in fact, ſo far from turning abſolutely round, that he keeps himſelf from turning at all; and the ſhip turns round him, as round a fixed axis; although, with reſpect to the ſhip, he has a relative motion.

Fig. 2. is a ſmall plan, or flate view of the machine, in which, the ſame letters of reference are put to the wheels in it, as to thoſe in Fig. 1. for the conveniency of looking at both the figures, in reading the deſcription of them. *WSEN* is the round immoveable plate: *D* the immoveable wheel on the fixt axis in the center of that plate: *E* the thick moveable wheel, whoſe teeth take into the teeth of the wheel *D*; and *F* is one of the thin wheels, over which *G* and *H* may be put; and then, *F*, *G*, and *H* will make a thickneſs equal to the thickneſs of the wheel *E*, and its teeth will take equally deep into the teeth of them all. The frame that holds theſe wheels is repreſented by the parallelogram *abcd*; and if it be turned round, it can give no motion to the wheel *D*, becauſe that wheel is fixt on an axis which is fixt into the great immoveable plate.

Take away the thick wheel *E*, and leave the wheel *F* where it lies, on the lower plate of the frame. Then turn the frame round the axis of the immoveable plate *WSEN* (denoted by *A* in Fig. 1.) and it will carry the wheel *F* round with it.—In doing this, *F* will ſtill keep one and the ſame ſide toward the fixt central wheel *D*, as the moon ſtill keeps the ſame ſide toward the earth: and although *F* will then have no relative motion with reſpect to the moving frame, it will be abſolutely turned round its own center *g* (like the man on the ſhip whilſt he ſtood without moving his feet on the deck) for the croſs mark on its oppoſite ſide will be progreſſively turned toward all the ſides of the room.

But, if we would keep the wheel *F* from turning round its own center, and ſo cauſe the croſs mark upon it to keep always toward one ſide of the room; or, like the magnetic needle, to keep the ſame point ſtill toward one fixed point in the horizon; we muſt produce an effect upon *F*, reſembling what the man on the ſhip did, by endeavouring to turn himſelf round the contrary way to that which the ſhip turned, ſo as he might keep from turning at all; and by that means, keep his face ſtill toward one and the ſame point of the horizon—And this is done, by making the numbers of teeth equal in the wheels *D* and *F* (ſuppoſe 20 in each) and putting the thick wheel *E* between them, ſo as to take into the teeth of them both. For then, as the frame is turned round the axis of the fixed wheel *D*, by means of the knob *n*, the wheel *E* is turned round its axis by the wheel *D*; and, for every ſpace of a tooth that the frame would turn the wheel *F*, in direction of the motion of the frame, the wheel *E* will counteract that motion, by turning the wheel *F* juſt as far backward with reſpect to the motion of the frame; and ſo will keep *F* from turning any way round its own center: and the croſs mark near its edge will be always directed towards one ſide of the room.—Whether the wheel *E* has the ſame number of teeth as *D* and *F* have, or any different number, its effect on *F* will be ſtill the ſame.

If *F* had one tooth leſs in number than *D* has, the effect produced on *F*, by the turning of the frame, would be as much more than counteracted by the intermediate wheel *E*, as is equal to the ſpace of one tooth in *F*: and therefore, whilſt the frame was turned once round, ſuppoſe in direction of the letters *W S E N* on the immoveable plate, the wheel *F* would be turned the contrary way, as much as is equal to the ſpace taken up by one of its teeth. But, if *F* had one tooth more in number than *D* has, the effect of the motion of the frame (which is to turn *F* round in the ſame direction with it) would not be fully counteracted by means of the intermediate wheel *E*; for as much of that effect would remain as is equal to the ſpace of one tooth in *F*: and therefore, in the time the frame was turned once round, the wheel *F* would turn, on its own center, in direction of the motion of the frame, as much as is equal to the ſpace taken up by one of its teeth: and here note, that the wheel *E* (which turns *F*) always turns in direction of the motion of the frame.

And therefore, if an upright pin be fixed into the lower plate of the frame, under the center of the wheel *F*, and if the wheel *F* has the ſame number of teeth that the fixt wheel *D* has, the wheel *G* one tooth leſs, and the wheel *H* one tooth more; and if theſe three wheels are put looſely upon this pin, ſo as to be at liberty to turn either way; and the thick wheel *E* takes into the teeth of them all, and alſo into the teeth of the fixt wheel *D*; then, whichever way the frame is turned, the wheel *H* will turn *the ſame way*, the wheel *G the contrary way*, and the wheel *F no way* at all.—The leſs number of teeth *G* has, with reſpect to thoſe of *D*, the faſter it will turn backward; and the greater number of teeth *H* has, with reſpect to thoſe in *D*, the faſter it will turn forward; reckoning *that* motion to be backward which is contrary both to the motion of the frame and of the thick wheel *E*, and *that* motion to be forward which is in the ſame direction with the motion of the frame and of the wheel *E*.—So that, the turning or not turning of the three wheels *F*, *G*, *H*, or the direction and velocity of the motions of thoſe that do turn round, depends entirely on the relation between their numbers of teeth and the number of teeth in the fixt wheel *D*, without any regard to the number of teeth in the moveable wheel *E*.

Having ſolved the paradox, and deſcribed the cauſe of the different effects which are produced upon the three wheels F, G, *and* H, *we ſhall now proceed to ſhew ſome uſes that be made of the machine.*

This machine is ſo much of an Orrery, as is ſufficient to ſhew the different lengths of days and nights, the viciſſitudes of the ſeaſons, the retrograde motion of the nodes of the moon's orbit, the direct motion of the apogeal point of her orbit, and the months in which the ſun and moon muſt be eclipſed.

On the great immoveable plate *A* (ſee Fig. 1.) are the months and days of the year, and the ſigns and degrees of the zodiac ſo placed, that when the annual-index *h* is brought to any given day of the year, it will point to the degree of the ſign in which the ſun is on that day.—This index is fixt to the moveable frame *B C*, and is carried round the immoveable plate with it, by means of the knob *n*. The carrying this frame and index round the immoveable plate, anſwers to the earth's annual motion round the ſun, and to the ſun's apparent motion round the ecliptic in a year.

The central wheel *D* (being fixt on the axis *a*, which is fixt in the center of the immoveable plate) turns the thick wheel *E* round its own axis by the motion of the frame; and the teeth of the wheel *E* take into the teeth of the three wheels *F*, *G*, *H*, whoſe axes turn within one another, like the axes of the hour, minute, and ſecond hands of a clock or watch, where the ſeconds are ſhewn from the center of the dial plate.

On the upper ends of theſe axes, are the round plates *I*, *K*, *L*; the plate *I* being on the axis of the wheel *F*, *K* on the axis of *G*, and *L* on the axis of *H*. So that, whichever way theſe wheels are affected, their reſpective plates, and what they ſupport, muſt be affected in the ſame manner; each wheel and plate being independent of the others.

The two upright wires *M* and *N* are fixed into the plate *I*; and they ſupport the ſmall ecliptic *O P*, on which, in the machine, the ſigns and degrees of the ecliptic are marked.—This plate alſo ſupports the ſmall terreſtrial globe *e* on its inclining axis *f*, which is fixed into the plate near the foot of the wire *N*. This axis inclines 23½ degrees from a right line, ſuppoſed to be perpendicular to the ſurface of the plate *I*, and alſo to the plane of the ſmall ecliptic *O P* which is parallel to that plate.

On the earth *e* is the creſcent *g*, which goes more than half way round the earth, and ſtands perpendicular to the plane of the ſmall ecliptic *O P*, directly facing the ſun *Z*: its uſe is to divide the enlightened half of the earth next the ſun from the other half which is then in the dark; ſo that, it repreſents the boundary of light and darkneſs, and therefore ought to go quite round the earth; but cannot, in a machine, becauſe, in ſome poſitions, the earth's axis would fall upon it.—The earth may be freely turned round on its axis by hand, within the creſcent, which is ſupported by the crooked wire *w*, fixt to it, and into the upper plate of the moveable frame *BC*.

In the plate *K* are fixed the two upright wires *Q* and *R*: they ſupport the moon's inclined orbit *ST* in its nodes, which are the two oppoſite points of the moon's orbit where it interſects the ecliptic *OP*. The aſcending node is marked ☊, to which the deſcending node is oppoſite, below *e*, but hid from view by the globe *e*. The half ☊ *T e* of this orbit is on the north-ſide of the ecliptic *OP*, and the other half *e S* ☊ is on the ſouth ſide of the ecliptic. The moon is not in this machine: but, when ſhe is in either of the nodes of her orbit in the heavens, ſhe is then in the plane of the ecliptic: when ſhe is at *T* in her orbit, ſhe is in her greateſt north latitude, and when ſhe is at *S*, ſhe is in her greateſt ſouth latitude.

In the plate *L* is fixed the crooked wire *UU*, which points downward to the ſmall ecliptic *OP*, and ſhews the motion of the moon's apogee therein, and its place at any given time.

The ball *Z* repreſents the ſun, which is ſupported by the crooked wire *XY*, fixt into the upper plate of the frame at *X*. A ſtraight wire *W* proceeds from the ſun *Z*, and points always toward the center of the earth *e*; but toward different points of its ſurface at different times of the year, on account of the obliquity of its axis, which keeps its paralleliſm during the earth's annual courſe round the ſun *Z*; and therefore muſt incline ſometimes toward the ſun, at other times from him, and twice in the year neither toward nor from the ſun, but ſidewiſe to him. The wire *W* is called *the ſolar ray*.

As the annual-index *h* ſhews the ſun's place in the ecliptic for every day of the year, by turning the frame round the axis of the immoveable plate *A*, according to the order of the months and ſigns, the ſolar ray does the ſame in the ſmall ecliptic *OP*: for, as this ecliptic has no motion on its axis, its ſigns and degrees ſtill keep parallel to thoſe on the immoveable plate. At the ſame time, the nodes of the moon's orbit *ST* (or points where it interſects the ecliptic *OP*) are moved backward, or contrary to the order of ſigns, at the rate of 19⅓ degrees every *Julian* year; and the moon's apogeal wire *UU* is moved forward, or according to the order of the ſigns of the ecliptic, nearly at the rate of 41 degrees every *Julian* year; the year being denoted by a revolution of the earth *e* round the ſun *Z*; in which time the annual-index *h* goes round the circles of months and ſigns on the immoveable plate *A*.

Take hold of the knob *n*, and turn the frame round thereby; and in doing this, you will perceive that the north pole of the earth *e* is conſtantly before the creſcent *g*, in the enlightened part of the earth toward the ſun, from the 20th of March to the 23d of September; and the ſouth pole all that time behind the creſcent in the dark: and, from the 23d of September to the 20th of March, the north pole is conſtantly in the dark, behind the creſcent, and the ſouth pole in the light before it: which ſhews, that there is but one day and one night at each pole, in the whole year; and that, when it is day at either pole, it is night at the other.

From the 20th of March to the 23d of September, the days are longer than the nights in all thoſe places of the northern hemiſphere of the earth which revolve thro' the light and dark, and ſhorter in thoſe of the ſouthern hemiſphere.—From the 23d of September to the 20th of March, the reverſe.

There are 24 meridian ſemicircles drawn on the globe, all meeting in its poles; and as one rotation or turn of the earth on its axis is performed in 24 hours, each of theſe meridians is an hour diſtant from the other, in every parallel of latitude.—Therefore, if you bring the annual-index *b* to any given day of the year, on the immoveable plate, you may ſee how long the day then is at any place of the earth, by counting how many of theſe meridians are in the light, or before the creſcent, in the parallel of latitude of that place; and this number being ſubtracted from 24 hours, will leave remaining the length of the night. —And if you turn the earth round its axis, all thoſe places will paſs directly under the point of the ſolar ray, which the ſun paſſes vertically over on that day, becauſe they are juſt as many degrees north or ſouth of the equator, as the ſun's declination is then from the equinoctial.

At the two equinoxes, *viz.* on the 20th of March and 23d of September, the ſun is in the equinoctial, and conſequently has no declination. On theſe days, the ſolar ray points directly toward the equator, the earth's poles lie under the inner edge of the creſcent, or boundary of light and darkneſs; and, in every parallel of latitude, there are twelve of the meridians, or hour-circles, before the creſcent, and twelve behind it; which ſhews that the days and nights then are each twelve hours long at all places of the earth. And, if the earth be turned round its axis, you will ſee that all places on it go equally through the light and the dark hemiſpheres.

On the 21ſt of June, the whole ſpace within the north polar circle is enlightened, which is 23½ degrees from the pole, all around; becauſe the earth's axis then inclines 23½ degrees toward the ſun; but the whole ſpace within the ſouth polar circle is in the dark: and the ſolar ray points toward the tropic of Cancer on the earth, which is 23½ degrees north from the equator.— On the 20th of December the reverſe happens, and the ſolar ray points toward the tropic of Capricorn, which is 23½ degrees ſouth from the equator.

If you bring the annual-index *b* to the beginning of January, and turn the moon's orbit *S T* by its ſupporting wires *Q* and *R* till the aſcending node (marked ☊) comes to its place in the ecliptic *O P*, as found by an Ephemeris, or by Aſtronomical tables, for the beginning of any given year; and then move the annual-index by means of the knob *n*, till the index comes to any given day of the year afterward, the nodes will ſtand againſt their places in the ecliptic on that day.—And if you move on the index till either of the nodes comes directly againſt the point of the ſolar ray, the index will then be at the day of the year on which the ſun is in conjunction with that node. At the times of thoſe new moons which happen within ſeventeen days of the conjunction of the ſun with either of the nodes, the ſun will be eclipſed: and at the times of thoſe full moons, which happen within twelve days of either of theſe conjunctions, the moon will be eclipſed.——Without theſe limits there can be no eclipſes either of the ſun or moon; becauſe, in nature, the moon's latitude, or declination from the ecliptic, is too great for the moon's ſhadow to fall on any part of the earth, or for the earth's ſhadow to touch the moon.

Bring the annual-index to the beginning of January, and ſet the moon's apogeal wire *UU* to its place in the ecliptic for that time, as found by Aſtronomical tables: then move the index forward to any given day of the year, and the wire will point on the ſmall ecliptic to the place of the moon's apogee for that time.

The earth's axis *f* inclines always toward the beginning of the ſign Cancer on the ſmall ecliptic *O P*. —And, if you ſet either of the moon's nodes, and her apogeal wire, to the beginning of that ſign, and turn the plate *A* about, until the earth's axis inclines toward any ſide of the room (ſuppoſe the north ſide) and then move the annual index round and round the immoveable plate *A*, according to the order of the months and ſigns upon it, you will ſee that the earth's axis and beginning of Cancer will ſtill keep toward the ſame ſide of the room, without the leaſt deviation from it; but the nodes of the moon's orbit *S T* will turn progreſſively towards all the ſides of the room, contrary to the order of ſigns in the ſmall ecliptic *O P*, or from eaſt, by ſouth, to weſt, and ſo on: and the apogeal wire *UU* will turn the contrary way to the motion of the nodes, or according to the order of the ſigns in the ſmall ecliptic, from weſt, by ſouth, to eaſt, and ſo on quite round.—A clear proof that the wheel *F*, which governs the earth's axis and the ſmall ecliptic, does not turn any way round its own center; that the wheel *G*, which governs the moon's orbit *O P*, turns round its own center backward, or contrary both to the motion of the frame *B C* and thick wheel *E*; and that the wheel *H*, which governs the moon's apogeal wire *UU*, turns round its own center, forward, or in direction both of the motion of the frame, and of the thick wheel *E*, by which the three wheels, *F*, *G*, and *H*, are affected.

The wheels *D*, *E*, and *F*, have each 39 teeth in the machine; the wheel *G* has 37, and *H* 44; as ſhewn in Fig. 3.

The paralleliſm of the earth's axis is perfect in this machine; the motion of the apogee very nearly ſo; the motion of the nodes not quite ſo near the truth, tho' they will not vary ſenſibly therefrom in one year.—But they cannot be brought nearer, unleſs larger wheels, with higher numbers of teeth, are uſed.

In nature, the moon's apogee goes quite round the ecliptic in eight years and 312 days, in direction of the earth's annual motion; and the nodes go round the ecliptic, in a contrary direction, in eighteen years and 225 days.—In the machine, the apogee goes round the ecliptic *O P* in eight years and four-fifths of a year, and the nodes in eighteen years and a half.

Notwithſtanding the difference of the numbers of teeth in the wheels *F*, *G*, and *H*, and their being all of equal diameters, they take tolerably well into the teeth of the thick wheel *E*, becauſe they are made of ſoft wood.—But, if they were made of metal, the wheel *E* in Fig. 1. ought to be made of the ſhape of *E* (ſeen edgewiſe) in Fig. 3. with very deep teeth: and the wheels *F*, *G*, and *H*, in Fig. 1. of diameters proportioned to their reſpective numbers of teeth, as *F*, *G*, and *H*, in Fig. 3. And then, the teeth of theſe three wheels would be of equal ſizes with thoſe of the wheel *E* wherein they work: and the motions would be free and eaſy, without any pinching or ſhake in the teeth.

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